

# **THE RETRIEVAL OF THE STRUCTURE AND OPTICAL PROPERTIES OF AEROSOLS IN THE LOWER PART OF THE MARINE ATMOSPHERIC BOUNDARY LAYER (LP MABL) FROM REAL DATA OF AEROSOL MEASUREMENTS**

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## **LONG-TERM GOAL**

The ultimate goal of our investigation is to establish correlations between the environmental factors (temperature, humidity, wind, waves, etc.) and aerosol optical characteristics in the lower tens of meters of the marine atmospheric boundary layer (LP MABL).

## **SCIENTIFIC OBJECTIVES**

The scientific objective was to develop methods of using real experimental optical data for the determination of the aerosol structure in LP MABL.

## **APPROACH**

The problem of deriving information on the aerosol particle size distribution (APSD) in LP MABL depends on a priori data for this layer. Our approach was to develop methods capable of using experimental information available in a most efficient way in order to extract maximum knowledge of aerosol structure and optical properties of LP MABL.

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## WORK COMPLETED

Our work was concentrated on the following problems:

- I) The development of methods of inverting scarce, incomplete and/or low-accuracy data into APSD in LP MABL. The methods are intended for dealing with experimental optical data which are often insufficiently detailed and accurate to be inverted by common methods.
- II) The analysis of experimental optical data with the objective to obtain aerosol microphysical characteristics in LP MABL;
- III) The analysis of correlation between values of aerosol spectral transmittance in LP MABL at different spectral ranges with the objective to predict the transmittance in one range from data for another one.

I. Optical characteristics of aerosol in LP MABL are affected by a significant number of particles of radii larger than  $10\text{ }\mu\text{m}$ . The kernel of integral equation determining the aerosol spectral transmittance is of such a nature that the retrieval of aerosol particle size distribution (APSD) requires data for wavelengths longer than  $5\text{ }\mu\text{m}$  when dealing with large particles. In cases when measurements are restricted to shorter wavelengths, it is necessary to resort to various artifices to determine the APSD tail, all of which result in extrapolation. Thus, one can expect only a tentative estimate of APSD for large particles when initial optical data are restricted to shorter wavelengths. In this situation, the use of the small-angle phase function is quite expedient. The function is very well suitable for being inverted into the large-particle part of distribution.

We developed an algorithm in a form of interactive procedure with a simultaneous inversion of the spectral attenuation at wavelengths as long as  $5\text{ }\mu\text{m}$ , and of the small-angle phase function in the  $5\text{-}6^\circ$  angular interval for the visible range. The algorithm was tested for its stability to arbitrary measurement errors. A methodology was developed for data processing of the small-angle function containing errors, which is applicable to real measurement data. As a result, we obtained quite a promising method for determining the entire APSD in LP MABL.

The constrained inversion method for the spectral transmittance is stable to arbitrary errors only to a certain degree. The stability holds until the smoothing of error-burdened data leads to essential distortions of an actual spectral curve. Starting at an error of 5%, the distortions become so significant that the inversion loses stability in spite of regularization. The system of equations becomes incompatible. The resulting solutions oscillate so intensely that it becomes impossible to obtain a reliable answer. The same takes place when the measurement range is too narrow.

We developed a method that takes care of the described situation and makes it possible to derive information on APSD when experimental data are not sufficiently accurate and/or complete. We proceeded from the present-day knowledge of the aerosol in LP MABL. The APSD in LP MABL can be described by a sum of three log-normal distributions. The ranges for APSD parameters are specified basing on a concrete meteorological situation of the experiment and on the current aerosol models. The values of optical characteristics and error intervals are found by the data processing of the measured signal. Optical characteristics are calculated by the Mie formulas using the APSD parameters within the above-established ranges. The APSD models are

selected whose optical characteristics fall within the previously found error range. We developed a procedure making it possible to determine the most probable APSD models and their accuracy.

II. We chose for the analysis two sets of horizontal spectral transmittance observations in coastal areas: Denmark, 1994 (in the 2.5-14  $\mu\text{m}$  spectral range) and Scotland, 1949 (1-14  $\mu\text{m}$ ). The gas absorption was excluded with LOWTRAN 7. In some cases, the measured atmospheric transmittance turned out to be higher than the gas transmittance calculated by LOWTRAN 7 for the conditions of the experiments, that is the aerosol attenuation derived took negative values. Taking account of the Forbes and scattering effects proved to be insufficient to compensate for this paradox. The prevalence of the measured atmospheric transmittance over calculated gas transmittance occurred in the Denmark experiment more often than in the Scotland one. For the further analysis, such cases were discarded.

The aerosol attenuation obtained from the Scotland experiment proved to be inverseable by the common constrained method at the 1-2.3  $\mu\text{m}$ . For the Denmark experiment and for the 8-14  $\mu\text{m}$  Scotland measurement band, the inversion turned out to be possible only by our above-described inversion method for low-accuracy data. Additionally, the Denmark inversion results showed discrepancies between APSDs obtained from the measurements at different spectral bands. They also differed from those obtained by direct measurements during the experiment. The spectral behavior of the aerosol attenuation calculated from these APSDs contradicted the behavior of aerosol attenuation calculated from the measured atmospheric transmittance. The character of the above-noted discrepancies implies that the measurements contained, together with random errors, systematic ones causing spectral distortions.

III. The above-described inversion algorithm was also used for analyzing the possibility of predicting the aerosol attenuation at a certain spectral interval from the attenuation known at another interval. For this purpose, the correlation matrix between aerosol spectral attenuation values at different spectral intervals was studied.

The matrices constructed for specific environmental conditions are governed by sets of APSDs, each set is characteristic of a concrete matrix. The APSDs act as transfer functions of a sort, correlating the aerosol spectral attenuation at different spectral ranges. An APSD set satisfying attenuation values within a certain spectral range is determined by our inversion method for scarce data. From these APSDs, the spectral attenuation for a different spectral range is calculated. The ensemble of attenuation values obtained in this manner is used for constructing the correlation matrix. The matrix obtained depends exclusively on the APSDs shape, and this is where it differs from experimental matrices. The joint analysis of theoretical and experimental matrices allows one to conclude what kinds of aerosol are viewed in an experiment with respect to environmental conditions. A program for the calculation of the correlation matrix by the above-described method has been developed.

## RESULTS

1. An algorithm for simultaneous inversion of the spectral attenuation in a range of visible to 5 $\mu\text{m}$  wavelengths and small-angle phase function in the 5-6° angular interval for the visible range has

been developed. The algorithm was tested for its stability to arbitrary measurement errors. A methodology has been developed for data processing of the small-angle function containing errors. The methodology is applicable to real experimental data. The method developed has proved to be quite promising for determining the APSD in LP MABL for the entire aerosol particle size interval [1,2,6].

2. An inversion method for insufficient and/or low accuracy optical data has been developed. The method was tested with real experimental data and proved to be efficient. It also makes possible to retrieve the APSD in LP MABL from the backscattered lidar signal [3,4,8,9].

3. The analysis of experimental data in Denmark and Scotland has been performed. Certain systematic spectral distortions of the measurement results have been detected, particularly so in the Denmark experiment. Recommendations for IR measurements in the LP MABL intended for obtaining information on the aerosol particles were worked out [2,5,7,10].

## **IMPACT/APPLICATION**

1. The method of simultaneous inverting the spectral transmittance and the small-angle phase function is novel. It retrieves the APSD in the entire particle size interval with a good accuracy. The method is particularly suitable for LP MABL where a significant amount of large particles is present.

2. The method for inverting scarce and/or low-accuracy data is also novel. It allows one to derive information on the aerosol structure from real experimental data, even from those of a low quality. In particular, this has implications for analyzing lidar observation data that use one or several measurement wavelengths.

## **TRANSITIONS**

Our method of retrieving the particle size distribution from incomplete optical data is used for studying the size distribution of atmospheric aerosols by the following scientists: Dr. Alexander Ignatov, NOAA/NESDIS;

Dr. Roman Glazman, Jet Propulsion Laboratory; Prof. Jacqueline Lenoble, Un. des Science et Technologie de Lille, France; Prof. Anatoly Gitelson, Remote Sensing Laboratory, Ben-Gurion University, Israel.

Our method of retrieving the particle size distribution by the simultaneous use of spectral transmittance and small-angle phase function is employed by the following scientists: Dr. Philip D. Hopke, Dept. of Chemistry, Clarkson University, for the study of colloid systems; Prof. Pierro Bruscaiglione, Istituto Fisica Superiore, Italy, for the study of the atmospheric aerosol size distribution; Prof. Rodolfo Guzzi, Istituto per lo studio delle Metodologie Geofisiche-Ambientali IMGA CNR, Italy, for the study of atmospheric aerosols; Dr. Glaucio Tonna, Istituto di Fisica dell'Atmosfera, Italy, for the study of atmospheric aerosol and hydrosol; Dr. O.V.Kopelevich, Institute of Oceanology of the Russian Academy of Sciences, for the study of hydrosol; Dr. I.M.Levin, Institute of Oceanology of the Russian Academy of Sciences, for the

study of atmospheric aerosols and hydrosol.

## **RELATED PROJECTS**

The results obtained will be used in the ONR-funded project "The determination of the microphysical characteristics of aerosols in the lower part of the marine atmosphere boundary layer from the structure of the backscattered lidar signal" and the NASA-funded study "The improved algorithm for estimating the atmospheric effect in space measurements of the marine chlorophyll concentration."

## **REFERENCES**

1. Shifrin K.S., and Zolotov I.G. (1997): The determination of the aerosol particle size distribution from simultaneous data on the spectral attenuation and small-angle phase function, *Applied Optics*, 36, No. 24, 6047-6056.
2. Shifrin, K.S. (1997): Atmospheric aerosol, methods of sampling and analysis. In: *The Encyclopedia of Environmental Analysis and Remediation*; John Wiley & Sons Inc.; New York, (in print).
3. Osadchy V., Shifrin K., and Gurevich I. (1997): Remote infrared laser sensing of oil film on the sea surface (submitted to *Oceanologica Acta*).
4. Levin I.M., and Shifrin K.S. (1997): Possibility of determining sea water absorption by satellite-based pulsed lidar (submitted to *Remote Sensing of Environment*).
5. Carlson R., Shifrin K., and Zolotov I. (1997): The retrieval of the aerosol particle size distribution in the lower part of the marine atmospheric boundary layer from experimental data on the horizontal spectral transmittance (in preparation).
6. Shifrin K.S., and Zolotov I.G. (1997): The retrieval of the aerosol particle size distribution in the lower part of the marine atmospheric boundary layer from the lidar backscattered signal at two wavelengths (in preparation).
7. Shifrin K.S., Zolotov I.G. (1996): The method for the retrieval of the aerosol particle size distribution (APSD) in the marine atmosphere boundary layer (MABL) from optical measurement data. Abstracts of "Ocean Optics XIII" in Halifax, Oct. 1996, p. 11.
8. Kokorin A.M., Shifrin K.S. (1996): The backscattering of suspended marine particles. Abstracts of "Ocean Optics XIII" in Halifax, Oct. 1996, p. 43.
9. Shifrin K.S. (1997): The identification of individual components of the measured radiance of the ocean-atmosphere system (SPIE, abstract).
10. Carlson R., Shifrin K., and Zolotov I. (1997): The retrieval of the aerosol particle size distribution in the lower part of the marine atmospheric boundary layer from horizontal measurements of the atmospheric spectral transmittance in the IR range (SPIE, abstract).